Micro-Raman-Photoluminescence Study of Mg-doped GaN Materials Prepared by Metal Organic Chemical Vapor Deposition

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Recently, a great deal of developments have been made in III-Nitride based optoelectronic materials and devices. An important breakthrough among these achievements is the success of p-type doping in epitaxial GaN [1,2], which is the base to realize device applications. It was found that hydrogen present in the metal organic chemical vapor deposition (MOCVD) growth environment passivates Mg acceptors. It is necessary to have a postgrowth treatment to electrically activate the acceptors, such as low-energy electron beam irradiation [1] or a nitrogen-gas-ambient thermal annealing above 700°C [2]. Rapid thermal annealing (RTA) has also been used for the activation of Mg dopants in GaN [3,4]. The grown materials are needed to characterize via various techniques. We have explored various optical techniques for quick and non-destructive assessments on III-Ns [5-8]. We are here to investigate the Mg-doped p-type GaN epitaxial materials via the UV Raman-photoluminescence (PL). Two sets of p-GaN films grown on sapphire substrates by MOCVD are studied. A Renishaw UV micro-Raman-PL system excited by 325 nm from a HeCd laser was employed for measurements at room temperature (RT).

The first set with six Mg-doped GaN/sapphire, P1-P6, were prepared under different growth conditions, including source and carrying gas flow, temperature and pressure, in order to find the optimum growth parameters for Mg-doped GaN. Samples in the second set were cut from a same piece of Mg-doped GaN wafer but experienced different RTA temperatures, served to find the best RTA annealing condition. Hall measurements showed some primary trend of the data. We explored to use other more techniques to clearly obtain the optimum conditions from these samples. X-ray diffraction showed little difference among them, so did visible Raman scattering using excitation of 488, 514 and 633 nm [5]. Recently, we have succeeded to apply the infrared spectroscopy to analyse the Si-doped n-type GaN epi-films [6] but failed to obtain distinguished features between these two sets of p-GaN, which is also similar for photoreflectance (PR) [7]. Low temperature (LT) PL has served for our many studies on GaN [8]. However, the used LT-PL system is equipped with a scanning monochromator, photomultiplier (PMT) and lock-in electronics, and is not sensitive enough to obtain RT PL signals for the Mg-doped GaN from samples under this study. The new UV μ-Raman-PL system is equipped with charge coupled diode (CCD) detector with high sensitivity and is very suitable for the studies of III-N materials from our practice.

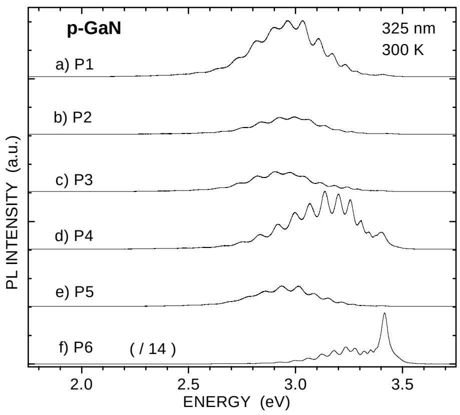

Figure 1. High sensitivity RT PL spectra from six Mg-doped GaN epi-films grown on sapphire by MOCVD. The intensity of P6 is reduced by a factor of 14.

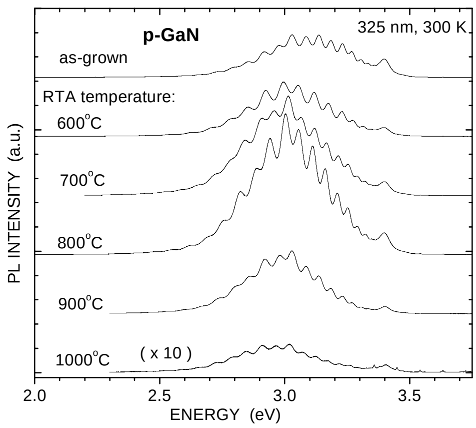

Figure 2. High sensitivity RT PL spectra from as-grown and RTA annealed Mg-doped GaN epi-films. The spectrum of RTA-1000°C is magnified by 10 times.

Figure 1 shows high sensitivity RT PL spectra from six Mg-doped GaN epi-films grown on sapphire by MOCVD. It is seen that the sample P6 possesses a strong 3.4-eV emission, which is due to the GaN band edge PL and a 3.2-eV broad band which was assigned to isolated Mg acceptors in GaN with Mg concentration in the low

10^{18} cm^{-3} range [9]. P4 has these two bands also but with different intensity ratios. These indicate that the device application required high concentration Mg-dopants are not reached in these two samples. P1, P2, P3 and P5 showed the 3.0-eV broad emissions, which are related to Mg acceptors in GaN materials with higher Mg-doping levels [10,11]. P1 has this band strongest, indicating the best Mg-doped sample among this series of samples. These are correlated to the electrical characterization of these samples (not shown here).

Figure 2 shows high sensitivity RT PL spectra from the second set of samples, including an as-grown Mg-doped GaN and five under RTA annealing with different temperatures. It is found that as T(RTA) increases from 600 to 700 and 800°C, the Mg-acceptor related 3.0-eV band increases in intensity. It decreases when T(RTA) goes to 900°C and decreases greatly at 1000°C. Thus, an optimum T(RTA) of 800°C is obtained.

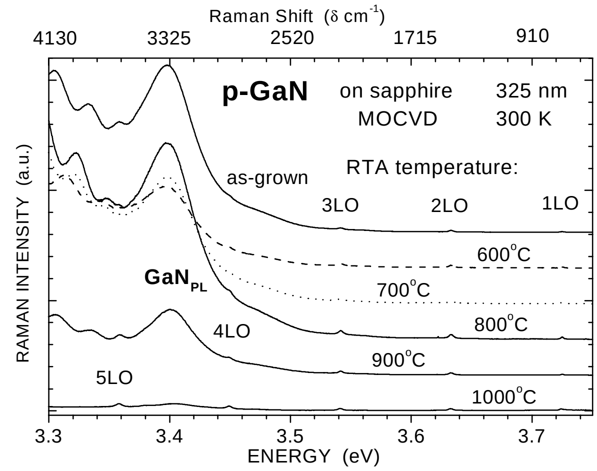

Figure 3. High sensitivity RT Raman spectra obtained from Fig. 2 for as-grown and RTA annealed samples.

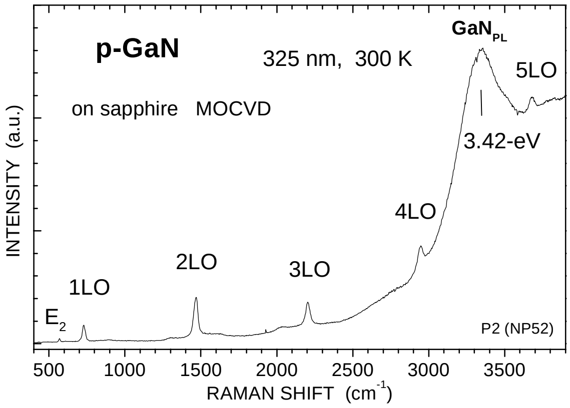

Figure 4. Resonance Raman spectrum of a Mg-doped p-type GaN epi-film, P2.

This μ-Raman-PL set can also measure both intense and weak signals at the same time. Figure 3 is made from Fig. 2, magnified and displayed for the range of 3.3-3.75 eV, i.e. in the Raman shift range of 400-4130 cm^{-1}. Multiple longitudinal optical (LO) phonons with A_1 symmetry are observed together with the GaN 3.42-eV PL band. It is found that the best RTA annealed p-GaN at 800°C shows the strongest mLO modes, corresponding to the strongest Mg-related 3.0-eV band. Therefore, these two factors can be together used as a merit of the quality of p-GaN epi-films. At the same focusing spot, Raman and resonance Raman scattering can be re-measured with longer accumulation time (still short, a few minutes) in better shape. Figure 4 shows such an example for p-GaN P2. The appearance of mLO modes is due to the outgoing resonance with the fundamental GaN near edge PL band and we have observed this type of resonant enhancement for different III-Ns [12]. Further investigation is in the way.

In summary, Mg-doped p-type GaN grown on sapphire by MOCVD is studied by use of a high sensitivity micro-Raman-PL instrument. Optimum control of the growth parameters can be quickly obtained through room temperature PL-Raman measurements. Two merits of the quality control of p-GaN are established, i.e. the intensity of the Mg-related 3.0-eV band and the strength of the multiple LO Raman phonons under 325 nm excitation. Rapid thermal annealing and effects are studied and an optimum RTA temperature of 800°C is obtained. More details will be given.

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